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Residual effects of slit tillage and subsoiling in a hardpan soil☆

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Abstract

Subsoiling and slit tillage can increase root growth through subsurface hardpans. In-row subsoiling fractures a section of the pan below the row. Slit tillage cuts a 3-mm-wide slit through the pan with a thin blade mounted on a shallow subsoil shank. Subsoiling is usually repeated annually. Slit tillage has been reported as an alternative to subsoiling that does not need to be repeated annually. This study was conducted to determine the longevity of the effects of tillage on a fine loamy Acrisol at Florence, South Carolina, USA. Corn (*Zea mays*) root growth, yield, and soil cone index were measured for 3 years in plots that had been slit tilled, in-row subsoiled, or no-tilled for 4 years immediately prior to the study. During the study, no plots were tilled. Three-year average corn yields were 5.08 Mg ha^{-1} for residual slit-tilled treatments, 5.34 Mg ha^{-1} for residual subsoiled treatments, and 5.07 Mg ha^{-1} for the no-tilled treatments. Three-year mean profile cone indices were 2.53 MPa for residual slit-tilled treatments, 2.51 MPa for residual subsoiled treatments and 2.61 MPa for no-tilled treatments. Only 10% of the slits could be found 3 years after tillage. The lack of persistence of the slits was a result of either slit infilling with sand from the Ap horizon or collapse of the slit walls. Roots grew to a depth of at least 0.95 m in all treatments. Root growth was not correlated with yield. In this soil, residual subsoiled treatments gave higher yields than no-tillage treatments, but residual slit tillage did not. If deep tillage is not performed annually, subsoiling would be better than not tilling, but slit tillage would not.

Keywords: Soil strength; Penetrometer; Deep tillage; Hardpan

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1. Introduction

Annual deep tillage, usually in-row subsoiling, is necessary in southeastern Coastal Plain hardpan soils to maintain a suitable rooting environment. The pans in these structureless soils occur just below the Ap horizon. Pans are genetic and are aggravated by traffic (Campbell et al., 1974). Reconsolidation of the hardpans generally occurs within 1 year (Threadgill, 1982) although traces of deep disruption can be seen for 1 or 2 years (Busscher et al., 1986). Deep tillage requires drafts of 15–25 kN per subsoil shank for 0.3–0.4 m deep subsoiling (Karlen et al., 1991a). Slit tillage has been shown to require only 75% of the draft of a conventional parabolic subsoiler (Karlen et al., 1991b). The draft reduction would contribute not only to fuel savings but also to lower capital equipment expenses through smaller tractors.

Less frequent tillage would also be desirable. Slit tillage in coastal areas of the Gulf of Mexico has proven effective by allowing roots to penetrate the pans, fill the slits, and maintain open channels for root growth for several years (Elkins et al., 1983). Slits can have a longevity of 5–6 years in some soils if they fill with organic residue from root growth. This eliminates the need for subsoiling every year.

The pans of the Gulf coastal areas are similar to those of the Atlantic Coastal Plain of the southern USA. Both begin just below the plow layer and extend to depths of 40–50 cm (Campbell et al., 1974; Elkins et al., 1983). Slit tillage thus has the potential to be as effective in the Atlantic as in the Gulf Coastal Plains. In a previous related study, Karlen et al. (1991b) showed that slit tillage allowed root penetration through the hardpan of the Norfolk soil of the Atlantic Coastal Plain. The slit-tilled treatments had a significantly higher mean yield than no tillage. Slit tillage yields were slightly higher than conventional subsoiling. However, during this previous study, slit tillage was performed annually; no residual effects were measured.

The objectives of this study were to examine the residual effects of slit tillage compared with conventional subsoiling and no tillage for 3 years following cessation of deep tillage. We wished to determine slit longevity in a southeastern Atlantic Coastal Plain soil, to compare the residual effects of slit tillage to subsoiling, and to determine whether the residual effects of either were better than not tilling at all.

2. Methods

Between 1986 and 1989, 20 treatments (Table 1) were applied to six-row plots in four replicates. Some were described and analyzed by Karlen et al. (1991b). The study was located on a Norfolk loamy sand (fine loamy Acrisol) at the Coastal Plain Research Center, Florence, SC, USA. The Norfolk soil has a hardpan below the plow layer. The pan was variable in the field of this study ranging from a loamy sand E horizon to a transitional layer grading from the E to a sandy clay loam Bt (Campbell et al., 1974). The pan can have root restricting strengths (2 MPa or greater) below 0.20 m, the Ap, and can extend to a depth of 0.40 m (Busscher et al., 1986).

Tillage treatments of the previous study (1986–1989) consisted of: (a) subsoiling to a depth of 0.40 m with a forward-angled, 25-mm-wide, straight subsoil shank with a 44-mm-

Table 1
Deep tillage and fertilizer (nitrogen and phosphorus) and lime placement[a] for the experimental treatments for 1986–1989 prior to this study

Slit			Subsoil			No-till		
Treat. no.	N+P	Lime	Treat. no.	N+P	Lime	Treat. no.	N+P	Lime
3	Deep	Deep	11	Deep	Deep	–	–	–
1	Deep	None	9	Deep	None	–	–	–
8	Shallow	Deep	16	Shallow	Deep	–	–	–
7	Shallow	Shallow	15	Shallow	Shallow	19	Shallow	Shallow
5	Shallow	None	13	Shallow	None	17	Shallow	None
2	None	Deep	10	None	Deep	–	–	–
6	None	Shallow	14	None	Shallow	18	None	Shallow
4	None	None	12	None	None	20	None	None

[a]Shallow placement is 5 cm deep and 5 cm to the side of the row; deep placement is injected at a depth of 0.3 m behind the subsoil shank. No-till could not have a deep treatment.

wide shoe (the subsoiling treatment); (b) subsoiling to a depth of 0.30 m while cutting a 3-mm-wide slit between the depths of 0.30 and 0.40 m (the slit treatment); (c) no tillage. We visually verified that the tillage treatments penetrated the subsoil hardpan (Karlen et al., 1991b). This allowed roots to grow through the pan and into the subsoil.

For this study, the residual effects of the tillage treatments were evaluated during the summer growing seasons of 1990–1992. Plots were not tilled during this study. Corn (*Zea mays* L. cv. 'Pioneer 3165') was planted into these plots on 27 March 1990, 26 March 1991, and 2 April 1992 with Case IH Early riser 800 series no-till planters. Row dimensions (0.75 m width, 18 m length) were those used by Karlen et al. (1991b). The randomized complete block design of the 1986–1989 experiment was maintained. Local weather data were recorded with an automated Campbell Scientific weather station (Campbell Scientific, Inc., Logan, UT) located about 60 m from the plots.

Subsoiling implements of the previous study disrupted zones of approximately 0.10 m width at the soil surface along the row. This was about 13% of the surface area. There was no other surface tillage in these plots. Weeds were controlled with pre-emergence applications of Roundup [glyphosate, η-(phosphonomethyl)glycine] or Gramoxone Extra (paraquat, 1,1′-dimethyl-4,4′-bipyridinium salts) and Lasso [alachlor, 2-chloro-η-(2,6-diethylphenyl)-η-(methoxymethyl)acetamide]. Granular fertilizer (0–12–36 with micronutrients) was broadcast at a rate of 335 kg ha^{-1} on 6 April 1990, 9 April 1991 and 6 April 1992. When the plants were approximately 0.5 m tall, a urea-NH_4NO_3 solution was applied in a band approximately 0.15 m from each row at a rate of 135 kg N ha^{-1}. Although the original experiment, conducted from 1986 to 1989, had different fertility treatments (Table 1), all treatments received the same fertilization regime during 1990 to 1992.

At tasseling (19 June 1990, 18 June 1991, and 9 July 1992), we dug pits at the ends of treatments 7, 15, and 19 to measure root growth. These treatments had been slit tilled, subsoiled, and no-tilled and had received the same fertility treatments since 1986 (Table 1). Root growth was measured by the trench profile method. This consisted of counting roots in 0.1 m × 0.1 m cells over a 1-m-deep, 0.4-m-wide profile centered on, and perpendicular to, a mid-plot row. Pits were also used to observe slit longevity.

Soil cone index readings were taken within 1 m of the root pit as soon after root counting as practical and after rain had moistened the profile. Cone index readings were taken on 6 September 1990, 10 July 1991, and 26 August 1992. We used a manually operated penetrometer with a 13 mm, 30° solid angle tip (Carter, 1967). Cone index readings were taken at 17 locations to a depth of 0.6 m. These locations were perpendicular to the two middle rows at 0.095 m intervals. Gravimetric water contents were also taken on these dates in the row and in the mid-row.

Corn yields were taken from the middle two rows of the plots on 28 September 1990, 11 September 1991, and 22 September 1992. We harvested corn with an Almaco plot combine (G.W.C. Inc., Nevada, IA). A Steinlite Model SS250 electronic meter (Fred Stein Laboratories, Atchison, KS) was used to measure grain moisture so that data could be corrected to 15.5%.

Yield data were analyzed using a randomized complete block design. Root count, cone index, and water content data were analyzed as split plot designs with tillage treatment as the main effect and position and depth as splits. Analysis was done with ANOVA and GLM procedures of the Statistical Analysis System Institute Inc. (SAS Institute Inc., 1990).

3. Results and discussion

3.1. Yield

Mean yields for residual slit tillage treatments were essentially the same as for no-tillage treatments for all 3 years of the experiment (Table 2). Yields for residual subsoiled treatments were significantly higher than no-tillage treatments for 1991 and for the 3 years as a whole. Yields for all 3 treatments were low and were similar in 1990. The overriding factor for 1990 was the dry period after tasseling (mid-June to mid-July, Fig. 1) that significantly reduced corn growth. Both 1991 and 1992 had rainfall patterns that were conducive to good growth for corn. Yields for the three treatments were not significantly different in 1992. This was expected since tillage effects diminish with time (Threadgill, 1982; Elkins and Hendrick, 1983).

No residual effects for yield were found in the fertility treatments or placement of fertilizer treatments (Table 1). In fact, with *Pr* values (the probability that treatments are different

Table 2
Mean tillage treatment yields (Mg ha^{-1}) for 3 years after deep tillage ceased

Tillage treatment	1990	1991	1992	Mean
Slit	1.75a	7.19ab	6.66a	5.19ab
Subsoil	1.85a	7.57a	6.94a	5.46a
No-till	1.75a	7.10b	6.68a	5.18b
Mean [a]	1.79c	7.33a	6.78b	

[a] Means within the row with the same letter do not differ at the 5% level.
Means within columns with the same letter do not differ at the 5% level.

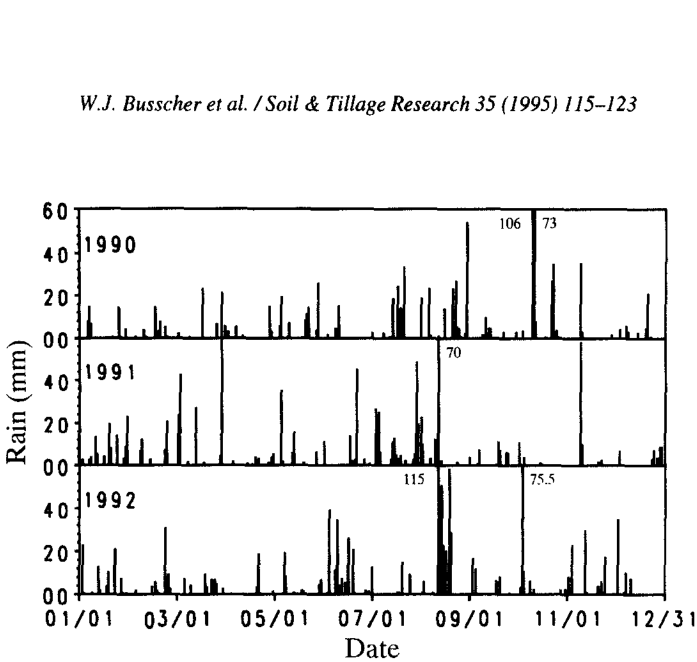

Fig. 1. Daily rainfall at the experimental site. The numbers next to some of the lines represent daily rainfall greater than 60 mm.

by chance) of over 0.59 for the fertility treatments and over 0.68 for the placement of fertilizer treatments, the effects were quite random.

3.2. Residual slits

In 1990, slits were easily found in pits dug for root counts. In 1991, 25% of the slits were found. By 1992 only 10% of the slits could be found. Slits that were found in 1992 did not always have roots growing in them. Slits were examined microscopically. The sides of the slits were smooth. About half of the remaining slits appeared to have sharp planes of weakness along their walls. They were filled with sand. The diameter of this sand was observed to be smaller than that found in the surrounding soil. It appeared that the slits were rendered ineffective after 3 years by collapse and/or by infilling with sand from above.

3.3. Cone indices

Water contents taken along with cone indices were not significantly different among treatments. For each date of measurement, water contents among treatments differed by less than 1% (data not shown) for each year. This was the result of waiting for rain before taking the cone index readings. Before the rain, readings consistently registered the maximum value of the penetrometer (9 MPa) below a depth of about 5 cm. Water contents differed significantly among years, ranked 1992 > 1991 > 1990 (16%, 13%, and 11%, respectively, on a dry weight basis).

The cone tip was 13 mm in diameter. Therefore, we did not expect it to register a low reading when it encountered a 3 mm slit since the reading would include the compacted

Table 3
Mean profile soil cone index (MPa) for 3 years after deep tillage ceased

Tillage treatment	1990	1991	1992	Mean
Slit	2.81a	3.07b	1.88a	2.53a
Subsoil	2.80a	2.89b	1.94a	2.51a
No-till	2.82a	3.46a	1.82a	2.61a
Mean [a]	2.81b	3.13a	1.88c	

[a] Means within the row with the same letter do not differ at the 5% level.
Means within columns with the same letter do not differ at the 5% level.

sidewalls. Slits themselves were evaluated in the nearby pits. Cone indices were used to measure the relative loosening of the profiles by the subsoilers.

Mean profile cone indices for tillage treatments are shown in Table 3. Though the mean cone indices for tillage treatments were approximately the same in 1990, the distributions of strength throughout the profile were significantly different. Cone indices were significantly different for position across the row, position by tillage treatment, depth within the profile, and depth by tillage treatment interactions. This can be seen in Fig. 2 by the increased cone indices below the mid rows and decreased cone indices below the row of the residual subsoiled treatment compared with the no-tilled treatment. The differences show up more readily for the residual subsoiled treatment since the shank disrupted the profile deeper than the shank of the residual slit-tillage treatment (Fig. 2).

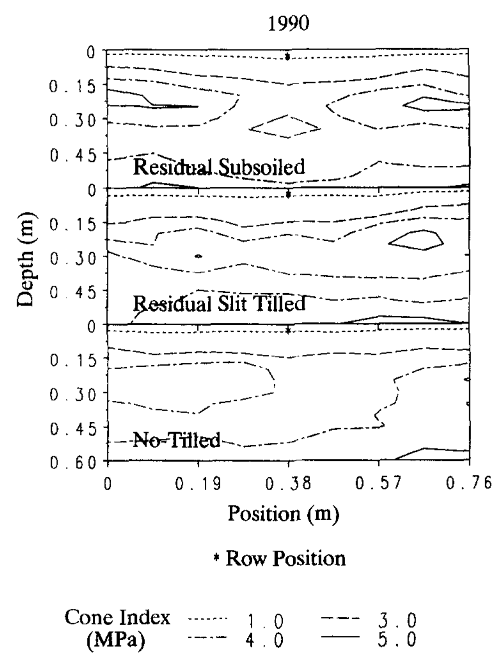

Fig. 2. Cone index contours perpendicular to the row and centered on mid-plot rows for 1990.

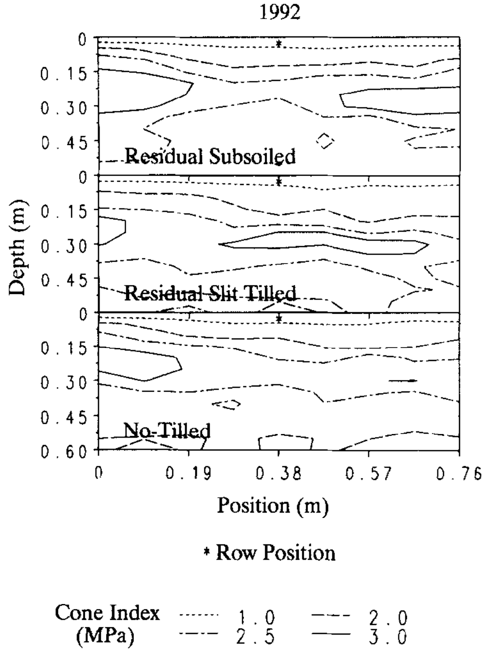

Fig. 3. Cone index contours perpendicular to the row and centered on mid-plot rows for 1992.

In 1991 the cone indices for tillage treatments, depth, depth by tillage treatment, and position were significantly different. However, position by tillage treatment was not significantly different. We cannot explain why there was a tillage treatment difference in 1991 when there was none in 1990 except to presume that it is due to the dry soil of 1990 or variability in the field. Since probing and root pits constituted destructive sampling, we moved to different locations within plots from year to year. The loss of significance for position by tillage treatment in 1991 indicated a loss of effect from tillage since disruption differences by various tillage tools would cause the variation across the row.

In 1992 the differences among tillage treatments were similar to 1991, except that the tillage treatments were not significantly different. In 1992, the reformed hardpan could be seen in all three treatments by the 2.5 MPa lines with lower cone indices above and below them (Fig. 3). The loss of the effects of tillage with time, the reconsolidation of the disrupted zone, has also been seen in earlier work (Threadgill, 1982; Elkins et al., 1983). The lower mean profile cone indices in 1992, compared with 1990 and 1991, were a result of the profile's higher water content at the time of probing.

3.4. Root data

One person counted roots in 1990 and 1991 and another in 1992. Root count at tasseling in 1992 was significantly lower than that of 1990 while yield for 1992 was significantly higher. We discounted differences among years but considered differences within years.

The no-tillage plots had not been tilled for at least the previous 7 years (i.e. the beginning of the previous experiment). Nevertheless, in all tillage treatments, even that of no tillage,

Table 4
Mean profile root count (number per 0.01 m^2) for 3 years after deep tillage ceased

	1990	1991	1992	Mean
Tillage treatment				
Slit	18.4a	22.3a	8.0a	16.3a
Subsoil	21.7a	20.7a	8.1a	16.8a
No-till	19.9a	24.1a	10.3a	18.1a
Mean [a]	20.0b	22.4a	8.8c	
Depth (m)				
0.5	65.7a	62.4a	28.5a	52.2a
0.15	38.4b	35.5b	10.8b	28.2b
0.25	18.3c	19.7c	8.5c	15.5c
0.35	13.2d	19.1c	8.6c	13.6cd
0.45	15.2d	18.7cd	8.1c	14.0cd
0.55	15.8cd	18.2cd	7.7c	13.9cd
0.65	13.6cd	19.8c	5.7d	13.0d
0.75	9.0e	15.2d	4.3de	9.5e
0.85	7.1e	10.5e	3.4ef	7.0f
0.95	2.3f	4.4f	2.4f	3.1g

[a] Means within the row with the same letter do not differ at the 5% level.
Means within columns with the same letter do not differ at the 5% level.

some roots penetrated the subsoil hardpan. No treatment had consistently significant increases in root count at any depth. The purpose of the slits was to provide a way for roots to penetrate the hardpan and maintain that path by a build-up of organic matter within the slit. Though many slits had roots growing through them, there were no root mats or concentrations of roots seen in the slits and thus no build-up of organic matter there as had been expected. The texture of soils (loamy sands) and depth of hardpans at locations where root mats kept the slits open from year to year (Elkins and Hendrick, 1983) were similar to this soil. However, here root densities at the depth of the pan were 8–19 roots per 0.01 m^2 (Table 4). These were not enough to provide a root mat that filled the slit or built up organic matter within them from year to year. Infilling of the slits by fine sand from above would also have thwarted filling by roots.

For all tillage treatments there were significantly more roots below the row (within ± 0.15 m of the row) than in the mid-rows (± 0.30–0.40 m from the row, data not shown). Root growth generally decreased with depth in all treatments. The decrease was not always inversely proportional with depth. There was always at least a slight drop in root growth near the depth of the pan, 0.25–0.55 m (Table 4). However, this difference was only significant for the no-tillage treatment of 1991 where root count was 37.4 per 0.01 m^2 at the 0.15 m depth, 15.9 per 0.01 m^2 at the 0.25 m depth, and 23.0 per 0.01 m^2 at the 0.45 m depth.

Root count measured at tasseling did not correlate well with yield (Tables 2 and 4). In 1991 and 1992, the no-tillage treatment had non-significantly higher root counts. Nevertheless, residual subsoiling outyielded the no-tillage treatment in both years.

4. Conclusions

Residual effects of subsoiling were seen 2 years after tillage by a significantly lower mean profile cone index and higher corn grain yield than for the no-tillage treatment. Though slits remained open for up to 6 years in the Gulf Coastal Plains (Elkins and Hendrick, 1983), this was not the case in the southeastern Atlantic Coastal Plain of the USA. Residual slit tillage (which included shallower subsoiling) did not outyield no tillage any year after tillage in the Atlantic Coastal Plain. Most of the slits did not persist with only 10% identifiable in 1992. The lack of slit persistence in this soil was due to collapse and infilling by sand.

Though the slit did not persist, slit tillage would be better than subsoiling if performed annually because it conserved energy and maintained or increased yield (Karlen et al., 1991b). If deep tillage is not to be performed annually, subsoiling would be better than not tilling since residual subsoiled plots outyielded no tilled plots, whereas residual slit tilled plots did not.

Root growth was observed to a depth of 0.95 m, the bottom of the observed zone, in all tillage treatments. However, no relationship was found between root growth and corn yield.

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